UNITED STATES MARINE CORPS
Utilities Instruction Company
Marine Corps Engineer School
Marine Corps Base
Camp Lejeune, North Carolina 28542-5040

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STUDENT HANDOUT

SOLID STATE POWER SUPPLIES

Terminal Learning Objective: Given a schematic, a faulty generator set electrical system, and applicable tools and test equipment, with the aid of references, repair the generator set electrical system so that it functions properly in accordance with the appropriate equipment technical manual. (1142.1.2)

Enabling Learning Objectives:

(1) Given a schematic diagram of a half wave rectifier and a list of rectifier characteristics, identify the characteristics that apply to the half wave rectifier, in accordance with FM 11-62. (1142.01.03bs)

(2) Given a schematic diagram of a conventional full wave rectifier and a list of rectifier characteristics, identify the characteristics that apply to the conventional full wave rectifier, in accordance with FM 11-62. (1142.01.03bt)

(3) Given a schematic diagram of a full wave bridge rectifier and a list of rectifier characteristics, identify the characteristics that apply to the full wave bridge rectifier, in accordance with FM 11-62. (1142.01.03bu)

(4) Given a list of circuit characteristics, identify the characteristics that apply to a simple capacitor filter, in accordance with FM 11-62. (1142.01.03bv)

(5) Given a list of circuit characteristics, identify the characteristics that apply to a shunt voltage regulator, in accordance with FM 11-62. (1142.01.03bw)

Outline:

1. Basic Power Supply:

a. Basic power supplies are made up of four sections; a transformer, rectifier, filter, and a regulator.

(1) The first section is the transformer. The transformer steps up or steps down the input line voltage and isolates the power supply from the power line.

(2) The rectifier section converts the A.C. input signal to a pulsating D.C. voltage.

(3) The filter section is used to convert the pulsating D.C. to a purer, more desirable form.

(4) The final section, the regulator, does just as the name implies; it maintains the output of the power supply at a constant level in spite of large changes in load current or input line voltages.

b. Now that you know what each section does, let's trace an A.C. signal through the power supply. You will see how this signal is altered within each section, and later you will see how these changes take place.

(1) The input signal of 115 volts A.C. is applied to the primary side of the transformer shown here. This transformer is a step-up transformer with a turn ratio of 1:3, therefore we get an output signal of 345 volts A.C. Because each diode in the rectifier section conducts for 180 degrees of the 360 degree input, the output of the rectifier will be one-half, or approximately 173 volts of pulsating D.C.

(2) The filter section, which is a network of resistors, capacitors, or inductors, controls the rise and fall time of the varying signal. Consequently, the signal remains at a more constant D.C. level. The output of the filter is a signal of 110 vdc.

(3) The regulator maintains its output at a constant 110 vdc.

2. <u>Half Wave Rectifier:</u>

a. Since a silicon diode will pass current in only one direction, it is ideally suited for converting alternating current to pulsating direct current.

(1) When A.C. voltage is applied to a diode, the diode conducts only on the positive alternation of voltage; that is, when the anode of the diode is positive in respect to the cathode.

(2) The simplest type of rectifier is the half-wave rectifier. It uses only one diode.

(a) During the positive alternation of input voltage, the same wave applied to the diode makes the anode positive with respect to the cathode. The diode conducts, allowing current to flow from the negative supply lead, through the diode, to the positive supply lead. This current exists during the entire positive alternation of input when the anode is positive in respect to the cathode.

(b) During the negative alternation of input voltage, the anode is driven and the diode cannot conduct. When this condition exists, the diode is cut off and remains cut off for the entire negative alternation of input, during which time no current flows in the circuit. The circuit current, therefore, has the appearance of a series of positive pulses. Although the current is in the form of pulses, the current always flows in the same direction. Current that flows in pulses in the same direction is called pulsating D.C. The diode has converted the A.C. input voltage, to pulsating D.C. output voltage.

b. The half-wave rectifier gets its name from the fact that it conducts during only half of the input cycle. Its output is a series of pulses with a frequency that is the same as the input frequency. Thus when operated from a 60 Hertz line, the frequency of the pulse is 60 Hertz. This is called ripple frequency.

3. Full Wave Rectifier:

a. A full-wave rectifier circuit uses two diodes, Dl and D2, and a center-tapped transformer TI. When the center tap is grounded, the voltages at the opposite ends of the secondary windings are 180 degrees out of phase with each other. Thus, when the voltage at point A is positive with respect to ground, the voltage at point B is negative with respect to ground. Now we can examine the operation of the circuit during one complete cycle.

b. During the first half cycle which is indicated by the solid arrows, the anode of Dl is positive with respect to ground and the anode of D2 is negative. As shown, current flows from ground (center tap), up through the load resistor (RL), through diode Dl, to point A. In the transformer, current flows from point A, through the upper winding and back to ground (center tap). When Dl conducts, it acts like a closed switch. The positive half cycle is felt across the load (RL).

c. During the second half cycle, (which is indicated by the dotted lines), the polarity of the applied voltage has reversed. Now the anode of D2 is positive with respect to ground and the anode of Dl is negative. Now only D2 can conduct. Current now flows, as shown, from the ground (center tap) up through the load resistor (RL) through diode D2 to point B of T1. In the transformer, current flows from point B, up through the lower windings and back to ground (center tap). Notice that the current flows across the load resistor (RL) in the same direction for both halves of the input cycle.

d. View (B) represents the output waveform from the full-wave rectifier. The waveform consists of two pulses of current for each cycle of input voltage. The ripple at the output of the full-wave rectifier is therefore twice the line frequency.

e. The higher frequency at the output of a full-wave rectifier offers a distinct advantage. Because of the higher ripple frequency, the output is closely approximate to pure D.C. The higher frequency also makes filtering much easier than it is for the output of the half-wave rectifier.

f. In terms of peak value, the average value of current and voltage at the output of the full-wave rectifier is twice as great as that of the half-wave rectifier. The relationship between the peak value and the average value is shown here in this slide. Since the output waveform is essentially a sine wave with both alternations at the same polarity, the average current or voltage is 63.7 percent of the peak current or voltage.

EXAMPLE: The total voltage across the high voltage secondary transformer used to supply a full-wave rectifier is 300 volts. Find the average load voltage (ignore the drop across the diode).

SOLUTION: Since the total secondary voltage (Es) is 300 volts, each diode is supplied one-half of this voltage or 150 volts. Because the secondary is an RMS value, the peak load voltage is:

E max = 1.414 x Es
E max = 1.414 x 150
E max = 212 volts

The average load voltage is:

E avg = 0.637 x E max
E avg = 0.637 x 212
E avg = 135 volts

g. Every electrical circuit has its advantages and disadvantages. The full-wave rectifier is no exception. In studying the full-wave rectifier, you may have found that by doubling the output frequency, the average voltage has doubled, and the resulting signal is much easier to filter because of the high ripple frequency. The only disadvantage is that the peak voltage in the full-wave rectifier is only half the peak voltage in the half-wave rectifier. This is because the secondary of the power transformer in the full-wave rectifier is center tapped; therefore, only half the source voltage goes to each diode.

4. The Bridge rectifier:

a. When four diodes are connected as shown here, the circuit is called a bridge rectifier. The input to the circuit is applied to the diagonally opposite corners of the network and the output is taken from the remaining two corners.

b. We will now look at one complete cycle of operation to help you understand how this circuit works. Let us assume the transformer is working properly. There is a positive potential at point A and a negative potential at point B. The positive potential at point A will forward bias D3 and reverse bias D4. The negative potential at point B will forward bias D1 and reverse bias D2. At this time, D3 and D1 are forward biased and will allow current flow to pass through them. D4 and D2 are reverse biased and will block current flow. The path for current flow is from point B, through Dl, RL, D3, the secondary winding of the transformer, and back to point B. This path is indicated by the solid arrows. Waveforms (1) and (2) can be observed across Dl and D3.

c. One-half cycle later, the polarity across the secondary of the transformer reverses. This will forward bias D2 and D4, and reverse biasing Dl and D3. Current flow will now be from point A, through D4, RL, D2, through the secondary of T1, and back to point A. This path is indicated by the broken arrows. Waveforms (3) and (4) can be observed across D2 and D4. As you will note, the current flow through RL is always in the same direction. In flowing through RL, this current develops a voltage corresponding to that shown in waveform

(5). Since current flows through the load (RL), during both cycles of the applied voltage, this bridge rectifier is a full-wave rectifier.

d. One advantage of a bridge rectifier over a conventional full-wave rectifier, is that with a given transformer, the bridge rectifier produces a voltage output that is nearly twice that of the conventional full-wave rectifier. This can be shown by assigning values to some of the components shown here in Figure (A) and (B). Assume that the same transformer is used in both circuits. The peak voltage developed between points X and Y is 100 volts in both circuits. In the conventional full-wave circuit, shown in Figure A, the peak voltage from the center tap to either X or Y, is 500 volts. Since only one diode can conduct at any instant, the maximum voltage that can be rectified at any instant is 500 volts. Therefore, the maximum voltage that appears across the load resistor is nearly, but never exceeds 500 volts, as a result of the voltage drop across the diode. In the bridge rectifier shown in Figure B, the maximum voltage that can be rectified is the full secondary voltage, which is 1000 volts. With both circuits using the same transformer, the bridge rectifier circuit produces a higher output voltage than the conventional full-wave rectifier circuit.

5. <u>Filters</u>:

a. While the output of a rectifier is a pulsating D.C., most electronic circuits require purer D.C. for proper operation. This type of output is provided by single or multisection filter circuits, placed between the output of the rectifier and the load.

b. There are four basic types of filter circuits: simple capacitor filter, LC choke-input filter, LC capacitor-input filter (PI type), and RC capacitor-input filter (PI type).

c. Filtering is accomplished by the use of capacitors, inductors, and/or resistors. Inductors are used as series impedance to oppose the flow of alternating, or pulsating D.C., current. Capacitors are used as shunt elements to bypass the alternating components of the signal around the load (to ground). Resistors are used in place of inductors in low current applications.

d. The simple capacitor is the most basic type of power supply filter. The application of the simple capacitor filter is very limited. It is sometimes used on extremely high voltage, low current power supplies for cathode ray and similar electron tubes which require very little load current from the supply. The capacitor filter is also used where the power supply ripple frequency is not critical. This frequency can be relatively high. The capacitor (C1), shown in this slide, is a simple filter connected across the output of the rectifier in parallel with the load.

e. When this filter is used the RC charge time of the filter capacitor (C1), must be short and the RC discharge time must be long, to eliminate ripple action. In other words, the capacitor must charge up fast, preferably with no discharge time at all. Better filtering also results when the input frequency is high; therefore, the full-wave rectifier is easier to filter than that of the half-wave rectifier because of its higher frequency.

f. The value of the capacitor is fairly large, thus it presents a relatively low resistance to the pulsating current and it stores a substantial charge. The rate of charge for the capacitor is limited only by the resistance of the conducting diode which is relatively low. Therefore, the RC charge time of the circuit is relatively short. As a result, when the pulsating voltage is applied to the circuit, the capacitor charges rapidly and almost reaches peak value of the rectified voltage within the first few cycle. The capacitor attempts to charge to the peak value of the rectified voltage any time a diode is conducting and tends to retain its charge when the rectifier output falls to zero. The capacitor slowly discharges through the load resistance during the time the rectifier is nonconducting.

g. The rate of discharge of the capacitor is determined by the value of capacitance and the value of the load resistance. If the capacitance and load resistance values are large, the RC discharge time for the circuit is relatively long.

h. A comparison of the waveforms shows here illustrates that the addition of Cl to the circuit results in an increase in the average of output voltage and reduction in the amplitude of the ripple component which is normally present across the load resistance.

i. Now let's consider a complete cycle of operation using a half-wave rectifier, a capacitive filter, and a resistive load. The capacitive filter is assumed to be large enough to ensure a small reactance to the pulsating rectified current. The resistance of RL, is assumed to be much greater than the reactance of Cl at the input frequency. When the circuit is energized, the diode conducts on the positive half cycle and current flows through the circuit, allowing Cl to charge. Cl will charge to approximately the peak value of the input voltage. The diode cannot conduct on the negative half cycle, because the anode of Dl is negative in respect to the cathode. During this interval, Cl discharges through the load resistor. In contrast to the abrupt fall of the applied A.C, voltage from peak value to zero, the voltage across Cl during the discharge period gradually decreases until the time of the next half cycle of rectifier operation.

j. Since practical values of Cl and RL ensure a more or less gradual decrease of the discharge voltage, a substantial charge remains on the capacitor at the time of the next half cycle of operation. As a result, no current can flow through the diode until the rising A.C. input voltage at the anode of the diode exceeds the voltage of the charge remaining on C1. The charge on Cl is the cathode potential of the diode. Then the potential on the anode exceeds the potential on the cathode from Cl, the diode again conducts and Cl begins to charge to approximately the peak value of the applied voltage.

k. After the capacitor has charged to its peak value, the diode will cut off and the capacitor will start to discharge. Since the fall of the A.C. input voltage on the anode is considerably more rapid than the decrease on the capacitor voltage, the cathode quickly becomes more positive than the anode and the diode ceases to conduct.

l. Operation of the simple capacitor filter using a full-wave rectifier is basically the same as that discussed for the half-wave rectifier. Looking at this diagram, you should notice that because one of the diodes is always conducting on either alternation, the filter capacitor charges and discharges during each half cycle. Still each diode conducts only for that portion of time when the potential on the anode exceeds the potential on the cathode, from the capacitor.

6. Regulators:

a. You should know that the output of a power supply varies with changes in input voltage and circuit load requirements. Because electronic equipment requires operating voltage and current which must remain constant, some form of regulation is necessary. Circuits which maintain power supply voltages or current outputs within specified limits or tolerances, are called regulators. They are designed as D.C. voltage or D.C. current regulators depending on their specific application.

b. Voltage regulator circuits are additions to basic power supply circuits, which are made up of rectifier and filter sections. The purpose of the voltage regulator is to provide an output voltage, with little or no variation. Regulator circuits sense changes in output voltages and compensate for the changes. Regulators that maintain voltages within plus or minus (+) 0.1 percent are quite common.

c. There are two basic types of voltage regulators. Basic voltage regulators are classified as either series or shunt, depending on the location or position of the regulating element, or elements, in relation to the circuit load resistance. This slide illustrates a series regulator. It is called a series regulator because the regulating device is connected in series with the load resistance. In practice the circuitry of regulating devices may be quite complex.

d. This schematic drawing is that of a shunt-type regulator. It is called a shunt-type regulator because the regulating device is connected in parallel with the load resistance. For the purpose of this course, we will deal primarily with the shunt regulator.

e. You already know the voltage drop across a fixed resistor remains constant unless the current flowing through it varies. In a shunt regulator, as shown here, output voltage regulation is determined through the parallel resistance of the regulating device (Dv), the load resistance (RL), and the series resistor (Rs). For now, assume that the circuit is operating under normal conditions. The input voltage is 120 volts D.C., and the desired regulated output is 200 volts D.C. For a 100 volt output to be maintained, 100 volts must be dropped across the series resistor, (Rs). If you assume that the value of Rs is 2 ohms, then you must have 10 amperes of current across Rv and RL. If the values of Rv and RL are equal, then 5 amperes of current will flow through each resistance.

f. Let's again look at the schematic diagram and consider how the voltage regulator operates, to compensate for changes in input voltage. You know, of course, that the input voltage may vary and that any variation must be compensated for by the regulating device. If an increase in input voltage occurs, there distance of Rv automatically decreases to maintain the correct voltage division between Rv and Rs. You see, the regulator operates in the opposite way to compensate for a decrease in input voltage.

g. If the load resistance RL increases the current through RL will decrease. For example, assume that the current through RL is now 4 amperes and that the total current across Rs is 9 amperes. With this drop in current, the voltage drop across Rs is 18 volts; consequently, the output of the regulator will increase to 102 volts. At this time, the regulating device (Rv), decreases in resistance and 6 amperes of current flows through this resistance (Rv). Thus, the total current is once again 10 amps. Therefore, 20 volts is dropped across Rs causing the output to decrease back to 100 volts. As you will notice, if the load resistance increases the regulating device decreases, to compensate for the change. If RL decreases, the opposite effect occurs and Rv increases.

h. Now consider the circuit when a decrease in load resistance takes place. Then RL decreases, the current through RL subsequently increases to 6 amperes. This action causes a total of 11 amperes to flow through Rs which then drops 22 volts. As a result, the output is 98 volts. However, the regulating device Rv senses this change and increases its resistance so that less current flows through Rv. The total current again becomes 10 amperes and the output is again 100 volts.

i. From these examples you should understand that the shunt regulator maintains the desired output voltage first by sensing the current change in the parallel resistance of the circuit and then by compensating for the change.

j. So far, only voltage regulators that use variable resistors have been explained. However, this type of regulation has limitations. Obviously, the variable resistor cannot be adjusted rapidly enough to compensate for frequent fluctuations in voltages. Since input voltages fluctuate frequently and rapidly, the variable resistor is not a practical method for voltage regulation. A voltage regulator that operates continuously and automatically to regulate the output voltage, without external manipulation, is required for practical application.

k . Looking at this diagram, you will notice that we have replaced the variable resistor with a transistor QI. We have also added a current limiting resistor, Rl, and a Zener diode CRI. As you will recall, a Zener diode is a diode which blocks current until a specified voltage is applied, which is referred to as breakdown or

Zener voltage. When the Zener voltage is reached, the zener diode conducts from its anode to its cathode. As we study this schematic you will notice that Rs is in series with the resistive load.
The current limiting resistor and the Zener diode, provide a constant reference voltage for the base collector junction of QI. Notice that the bias of Ql is determined by the voltage drop across Rs and RI. As you know, the amount of forward bias across a transistor affects its total resistance. In this case the voltage drop across Rs is the key to total circuit operation.

l. Notice that this schematic is identical to the one that we just saw, except the voltages are shown to help you understand the functions of the various components. In this circuit, the voltage drop across CRI remains constant at 5.6 volts. This means that with a 20 volt input voltage, the voltage drop across Rl is 14.4 volts. With a base emitter voltage of 0.7 volt, the output voltage is equal to the sum of the voltages across CRI and the voltage at the base emitter junction of QI. In this example, with an output voltage of 6.3 volts and a 20 volt input voltage, the voltage drop across Rs equals 13.7 volts.

m. View (A) is a schematic diagram of the same shunt voltage regulator we previously viewed, with an increased input voltage of 20.1 volts. This increases the forward bias on Ql to 0.8 volt. Recall that the voltage drop across CRI remains constant at 5.6 volts. Since the output voltage is comprised of the Zener voltage and the base emitter voltage, the output voltage momentarily increases to 6.4 volts. At this time, the increase in the forward bias of Ql lowers the resistance of the transistor, allowing more current to flow through it. Since this current must also pass through Rs, there is also an increase in the voltage drop across this resistor. The voltage drop across Rs is now 13.8 volts and therefore the output voltage is reduced to 6.3 volts. Remember, this change takes place in a fraction of a second.

n. In view (B), we have the same circuit except the output voltage is different. The load current has increased causing a momentary drop in voltage output to 6.2 volts. Recall that the circuit was designed to ensure a constant output voltage of 6.3 volts. Since the output voltage is less than that, changes occur in the regulator to restore the output to 6.3 volts. Because of the 0.1 volt drop in the output voltage, the forward bias of Ql is now 0.6 volt. This decrease in the forward bias increases the resistance of the transistor. This reduces the current flow through Ql by the same amount that the load current increased. The current flow through Rs returns to its normal value and restores the output voltage to 6.3 volts.

<u>References</u>:

1. FM 11-62